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Title:

USING CELLULAR NETWORK TO ESTIMATE TRAFFIC FLOW

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USING CELLULAR NETWORK TO ESTIMATE TRAFFIC FLOW

Background of the Invention

Technical Field of the Invention

The present invention relates generally to a system and method for estimating flow of e.g. automobile traffic, and more specifically to a system and method for doing so by using data from a cellular network such as a cellular telephone network.

Background Art

Cellular communications systems are known, such as cellular telephone systems. In some cellular systems, the communication area is divided into a number of cells. Each cell may be served by one or more communication sub-systems. In some embodiments, there may be some degree of overlap between adjacent cells. A communication device, such as a cellular telephone, communicates with one or more of these sub-systems. In some cases, a device may communicate with the cell sub-system which has the strongest communication signal at the location of the device. In some cases, the device may communicate with the nearest sub-system. In other cases, the device may communicate with a sub-system which is not the strongest and/or not the closest, for example to enable load balancing between the various sub-systems. In some cases, the device may be handed off from one sub-system to another, to permit dynamic load balancing.

Another common circumstance in which a device may be handed from one sub-system to another is the case of a mobile device which travels from one sub-system's area to another sub-system's area. As a device moves from one cell to another, the task of communicating with it is passed from one sub-system to another. In some cases, this may be centrally directed. In other cases, the sub-systems themselves may negotiate the handoff.

Cellular systems may be built using any wireless communication technique, whether it be via radio waves, broadband spread spectrum transmission, laser, satellite, or whatever suitable medium may be found for the particular application.

Most metropolitan areas are each divided into tens, hundreds, or thousands of cells. There may in many cases be overlapping entire cellular systems, such as one for consumer cellular telephones, one for industrial radios (such as the well-known Motorola radio system), and so forth.

1 FIG. 1 illustrates an exemplary map of a geographic area. The particular example given
2 happens to be the highway system in the Phoenix, Arizona metropolitan area, but that is, of course,
3 only one example.

4 Less intuitively, while the example is shown as a two-dimensional map adequate for
5 describing the generally two-dimensional road system, the invention may equally well be applied in
6 three dimensions, such as in the case of air travel. For ease of explanation, though, the
7 two-dimensional example will be the one described.

8 The highway system (generally indicated as 15) includes seven highways (Hwy 10, Hwy 60,
9 Hwy 17, Hwy 51, Hwy 143, Hwy 202, and Hwy 101) going to various destinations. The area does, of
10 course, include a multitude of smaller roads, but those are omitted from this explanation for clarity
11 and for ease of illustration. Hwy 10 includes non-linear segments connected at a series of turns. Hwy
12 60 includes two noncontiguous segments as illustrated; in actuality, the middle portions of Hwy 10
13 would likely be marked as belonging to both highways. Hwy 143 does not extend to any particular
14 external destinations, but serves only as a connector between two other highways.

15 FIG. 2 illustrates an overly simplistic example of a cellular system 20 which includes a
16 number of cells (A1-6, B1-6, ... F1-6). For simplicity, the cells are shown as being of equal size,
17 regular shape, and non-overlapping borders; in actuality, none of those are likely to be the case.

18 A cellular telephone customer traveling, for reasons known only to him, west to east from
19 Buckeye to Globe, would pass through cells C1, C2, D2, D3, D4, D5, E5, and E6 in succession. As
20 he reaches each cell boundary, the cellular system would hand him off from a prior cell to a next
21 current cell.

22 Of course, that customer is not likely to be the only cellular customer traveling the highways
23 of this map at this time. In actuality, there will generally be a very large number of cellular devices
24 traveling these roads at any given time. There will also be a number of cellular devices which are on
25 but which are not traveling, such as those in parked cars, in houses. There will generally also be
26 some number of customers who are driving around, but are staying within a single cell's boundaries;
27 in this case, these customers are not likely to be the ones using the highways, but are more likely to
28 be those on surface streets.

Brief Description of the Drawings

The invention will be understood more fully from the detailed description given below and from the accompanying drawings of embodiments of the invention which, however, should not be taken to limit the invention to the specific embodiments described, but are for explanation and understanding only.

FIG. 1 shows a map of the highway system.

FIG. 2 shows the highway system overlaid with a cellular grid.

FIG. 3 shows a block diagram of an exemplary system employing this invention.

FIG. 4 shows a flowchart of an exemplary method of operation of the system.

FIG. 5 shows a flowchart of another exemplary method of operating the system.

FIG. 6 shows a heuristic diagram of traffic flow vectors.

FIG. 7 shows an exemplary display such as may be used with the traffic estimation system or a cellular device used with such.

FIG. 8 shows an exemplary cellular device that embodies the invention.

FIG. 9 shows the highway system overlaid with the cellular grid, and shows highway cell boundary crossings.

Detailed Description

FIG. 3 illustrates one exemplary embodiment of a system 30 within which the present invention may be practiced. The system includes a cellular system 31 which includes a number of cellular sub-systems. The cellular system (and/or one or more of its sub-systems) maintains data 32 identifying which cellular devices are within the cells of which sub-systems, which may be termed cell occupancy data. The cellular system is in communication with a number of cellular devices 33 over any suitable communication medium 34 or media.

A traffic estimation system 35 is connected to receive the cell occupancy data from the cellular system, over any suitable communication mechanism 36. The traffic estimation system includes a cell map 37 identifying the locations of the cells in the cellular system. In one embodiment, the cell map may identify the locations of the cellular sub-systems such as the broadcast towers of such. In another embodiment, the cell map may define the boundaries of the cells. The skilled reader will, after gaining the teachings of this patent, be able to define a suitable cell map to suit a given application.

1 The traffic estimation system further includes a map 38 defining the two- or
2 three-dimensional area at hand. In the example given, this would be a road map identifying the
3 locations of the highways shown in FIG. 2. In one embodiment, the road map may be defined in
4 conventional cartographic terms, such as "highway 101 goes from point X to point Y" where X and
5 Y are expressed as Global Positioning System coordinates, longitude/latitude, or other suitable
6 terms. In another embodiment, the road map may be defined in terms of the associated cellular map
7 (or vice versa), such as "highway 202 goes from cell C6 to cell C5 to cell C4 to cell C3 to cell C2" or
8 the like. Again, after gaining the teachings of this patent, the skilled reader will be able to construct a
9 suitably configured road map to meet the given application.

10 The traffic estimation system includes a map overlay mechanism 39 which facilitates the
11 coordination of the cell map with the road map. In some embodiments, the overlay will be inherent
12 in the expression of one map in terms of the other, as in the highway 202 example in the preceding
13 paragraph.

14 The traffic estimation system includes a processing mechanism 40 for performing logic
15 operations of the method of the invention. In one embodiment, the processing mechanism may be a
16 single digital microprocessor. In another embodiment, it may take the form of a distributed algorithm
17 utilizing e.g. the processing power of the various cellular devices themselves. Other embodiments
18 will be apparent to the skilled reader.

19 The traffic estimation system includes a traffic flow analyzer 41 which performs analysis
20 upon the cell occupancy data in light of the road map and cell map. In one embodiment, the traffic
21 flow analyzer may simply be a computer program executing on the processing mechanism. In other
22 embodiments, it may be, for example, a dedicated hardware mechanism.

23 In some embodiments, the traffic estimation system may optionally include a traffic publisher
24 42 which communicates the results of the traffic analysis directly to one or more of the cellular
25 devices – such as those for which a subscription fee has been paid. In some embodiments, this
26 communication may utilize the existing cellular system, while in others, it may utilize a separate
27 back channel 43 or other communication link. The results may also be published to other entities,
28 such as a police department, department of transportation, a news bureau, a radio station, a television
29 station, a server computer, an internet website, or any other suitable recipient. In some such
30 embodiments, the results may be published to the internet 44 over any suitable connection 45.

1 As suggested in FIG. 3 by the direct connection of the traffic flow analyzer to the internet, in
2 some embodiments, the traffic flow analyzer may itself communicate the results rather than doing so
3 through a separate traffic publisher, and in some embodiments, there may be multiple publishing
4 links which may connect to different entities or a same entity within the traffic estimation system.

5 The reader will appreciate that the traffic estimation system may be incorporated as a part of
6 the cellular system, rather than as a stand-alone entity. It may even be embodied in the cellular
7 devices themselves, if desired.

8 FIG. 4 illustrates one exemplary method 50 of operation of the traffic estimation system or a
9 cellular device incorporating such. The traffic estimation system receives (51) the cell occupancy
10 data from the cellular system, then later receives (52) updated occupancy data. In some
11 embodiments, the entire data set may be received a second time, while, in others, only the delta or
12 changed data may be received. The skilled reader will appreciate that it may be desirable to use more
13 than two snapshots of the data, and that two snapshots or data sets are shown by way of illustration
14 only. If a cellular device is moving sufficiently slowly, or if the data sets are captured sufficiently
15 close in time, a two-set picture may not yield sufficiently useful data in some applications.

16 According to the differences or changes in the two data sets, the map overlay mechanism
17 categorizes (53) the cellular devices for which there are data. One categorization is to determine (54)
18 whether a given cellular device is moving from cell to cell. If it is moving, the overlay mechanism
19 compares (55) the cell occupancy data against the cell map, and the cell map against the road map, to
20 determine which of the highways the cellular device is traveling. The skilled reader will, of course,
21 appreciate that the overlay mechanism may be constructed to deal with probabilities rather than
22 absolutes. In other words, the overlay mechanism may determine that the given cellular device is
23 likely to be on the indicated highway, not necessarily that it is absolutely on that highway. The
24 probability may itself be characterized over a range of values, based on a variety of factors and other
25 data. For example, if the overlay mechanism determines (56) that the cellular device appears to be
26 traveling at fifteen miles per hour, and stopping every half mile for roughly the duration of a traffic
27 light, the overlay mechanism may deduce that the cellular device is on a surface street and not one of
28 the highways in question. Or, the overlay mechanism may notice that this particular cellular device is
29 traveling at only one third the velocity of other cellular devices which are believed to be on the
30 highway, and may therefore deduce that the particular device is not on the highway.

1 If (57) there are more cellular devices to be analyzed, operation may proceed (to 54) for each
2 of those devices in turn.

3 Once the entire set, or a sufficiently numerous set, of the available cellular devices'
4 occupancy data have been analyzed, the traffic flow analyzer can perform (58) aggregate device
5 analyses. For example, the traffic flow analyzer may determine that traffic on highway 202 has
6 ground to a halt, perhaps due to an automobile crash or the asphalt melting under the July sun. Or,
7 the traffic flow analyzer may determine that N automobiles are on highway 101 while only a small
8 fraction of that number are on highway 51, which goes to generally the same destination. As another
9 example, the traffic flow analyzer could determine that there is a trend of slower traffic at a point
10 where multiple routes converge. The skilled reader will appreciate a wide variety of usage models for
11 the traffic flow analyzer, and any number of specific data checks and analyses that it could perform.

12 Once the analysis has been performed, the traffic publisher may optionally publish (59) some
13 or all of the results to some or all of its subscribers or other entities. For example, the traffic
14 publisher may simply broadcast "avoid highway 101" or "highway 202 running smoothly" for the
15 world to see. However, that itself might cause problems, if an unduly large number of drivers heed
16 the advice, and suddenly highway 101 is wide open and highway 202 is bumper-to-bumper. Thus,
17 the traffic publisher may invoke any of a number of policies to prevent causing harm to the system.
18 For example, the results could be posted only to those subscribers who have even telephone
19 numbers. Or, they could be posted only to those subscribers presently in a particular cell area. The
20 traffic publisher could even publish misleading reports to subscribers who are more than sixty days
21 late making payment.

22 The method is, of course, not limited to this example. For example, the system could
23 additionally have the ability to isolate individual cellular devices and perform further analysis upon
24 them, perhaps even on an individual basis. In some such embodiments, it may be desirable to provide
25 a mechanism for performing individual analysis in an anonymized environment, to reassure
26 subscribers that their individual movements are not being tracked. Such additional analysis might
27 include, for example, redundancy checking or revalidating various assumptions that the system is
28 using. As another example, when the traffic flow analyzer determines that there is congestion at a
29 convergence point of multiple routes, it could further investigate movement of anonymized
30 individual cellular devices at that convergence point, to validate its determination with actual,
31 individual data.

1 FIG. 5 illustrates another example of a method 70 of operation of the traffic estimation
2 system (or a cellular device incorporating such, although the method will be described as being
3 practiced on a traffic estimation system, for simplicity). When the method is practiced in the traffic
4 estimation system, the system receives (71) a request for traffic flow estimation or analysis of an
5 area. This request may come from a cellular device, such as a customer inquiring what roads to
6 avoid, or it may come from another entity, such as a police department deciding where to send patrol
7 cars, or any other entity.

8 The traffic estimation system categorizes (72) the cellular devices in the specified area. In
9 some embodiments, no area is specified, and all areas can be categorized. The specification of an
10 area can be express, such as "tell me about traffic near the 202/101 interchange" or "tell me about
11 traffic in cell B3". Or, the specification can be inherently assumed, such as the area from which the
12 cellular device is making the request, or perhaps the area toward which the cellular device is heading.

13 In making the characterization, the traffic estimation system can filter out (73) cellular
14 devices in the specified area that have not recently been in other areas. This will tend to eliminate
15 from the traffic estimation those cellular devices which are not presently on the road and those which
16 are driving only within a localized area, such as those on surface streets, and those which have only
17 just been turned on.

18 The traffic estimation system captures or identifies (74) cellular devices newly arrived to the
19 area from other areas, and captures or identifies (75) cellular devices departing to other areas, which
20 are not to be included in the particular analysis or estimation being undertaken.

21 The traffic estimation system reconciles (76) the occupancy data of the specified area with
22 those of nearby or adjacent areas. From the resulting, filtered data, the traffic estimation system may
23 produce (77) a set of vectors (described below with regard to FIG. 6), analyzes those, and provides
24 (78) the resulting analysis to the requesting entity.

25 In some embodiments, these vectors may be converted (79) to a more visually meaningful
26 road map format prior to being sent to the requesting entity, or by the requesting entity itself, to
27 provide (80) a qualitative interpretation of the estimated traffic flow.

28 FIG. 6 illustrates, in diagrammatic form, one exemplary set of vectors describing traffic flow
29 from on cell (C3) to surrounding cells. The vectors may be represented graphically, or numerically,
30 or in any suitable manner. In the embodiment illustrated, the width of a vector may represent the
31 volume of traffic flowing in the indicated direction to the nearby or adjacent cell, while the length of

1 the vector may represent, for example, an average or maximum speed of vehicles traveling in that
2 direction. Thus, by referring to FIG. 6 and FIG. 2, it can be determined that the FIG. 6 vectors
3 indicate that traffic on westbound Hwy 202 (from C3 to C2) is heavy but moving, traffic on
4 eastbound Hwy 202 (from C3 to C4) is light and moving very rapidly, traffic from C3 to B4 is
5 almost nonexistent (which is to be expected, as there is no highway connecting those cells, and thus
6 the vector may be ignored for highway traffic analysis purposes), and so forth.

7 By performing such analysis on a number of the cells, a more complete traffic picture can be
8 constructed. For example, the analysis on C4 would include results for a C4-to-C3 vector, yielding
9 data about traffic flowing into cell C3 (whereas the simplistic example in the prior paragraph only
10 concerned traffic flowing out of cell C3). This will give deeper insight into traffic along longer
11 stretches of a given highway, as well. For example, if traffic from C3 to C2 is very heavy but
12 moving, but traffic from C2 to C1 (not shown, but is to the left of C2) is extremely heavy and hardly
13 moving at all, it can be deduced that there is a problem such as a crash or a closed lane farther to the
14 west than C3, and that some of the C4-to-C3 traffic should be diverted in order to miss that event.

15 FIG. 7 illustrates one exemplary graphical or video display 92 such as may be presented at a
16 cellular device or other requesting or monitoring entity. The display may include a road map 93
17 displayed in any suitable format, or in some embodiments a cell map (not shown) either alone or
18 overlaid with the road map. In embodiments in which the display is part of or used in conjunction
19 with the cellular device, the display may advantageously include a "you are here" indicator 95 and a
20 destination indicator 98.

21 The map display may further include one or more "avoid this road" indicators such as mark
22 96, and/or one or more "suggested route" markers such as arrow 97. These may be derived from the
23 vectors or other traffic flow analysis results, as appropriate.

24 In some embodiments, the display 92 may further or alternately include a textual display area
25 94 for displaying message information. The message information may, or may not necessarily, relate
26 to the graphical indicators such as 96 and 97.

27 In some embodiments, the display may be used in conjunction with a Global Positioning
28 System (GPS) or other such positioning apparatus. The GPS may be used, for example, to accurately
29 place the "you are here" indicator and/or to orient the map in "direction of travel UP" mode (as
30 opposed to "north UP" mode).

1 FIG. 8 illustrates one exemplary embodiment of a cellular device 110 adapted to perform the
2 method of this invention. The cellular device includes a receiver 111 and a transmitter 112 for
3 communicating with the cellular system. In some embodiments, the cellular device may include a
4 separate communication mechanism (not shown) for back-channel communication with a traffic
5 publisher (42 in FIG. 3), or the receiver and transmitter may be modified to incorporate such.

6 The cellular device may further include a processor 113 for performing logical operations,
7 including some or all of the logic operations of the method of this invention, and typically also other
8 operations for conventional cellular usage and the like.

9 The cellular device may include an input 114 such as a keypad, and an output 115 such as a
10 liquid crystal display for presenting maps and other data to the user.

11 The cellular device may further include one or more types of memory 116, such as random
12 access memory, read-only memory, flash memory, rotating storage, polymer ferro-electric memory,
13 optical storage, magnetic storage, or any other suitable memory devices. The memory may include
14 data comprising a road map 117 in any suitable format, data comprising a cell map 118 in any
15 suitable format, a map overlay mechanism 119, a traffic flow analyzer 120, a requestor 121 for
16 issuing requests (such as for updated traffic analysis, or for refreshed road or cell map data) to the
17 traffic analysis system or the cellular system, and data representing cell occupancy data 122.

18 The input 114 may include one or more controls, such as buttons or other suitable controls
19 for zooming the display in and out, buttons or other suitable controls for scrolling the display up,
20 down, left, and right, and so forth. These are well within the abilities of those having ordinary skill in
21 the relevant arts, and thus will not be discussed in detail here.

22 FIG. 9 illustrates, in diagrammatic form 130, one alternative method of representing the road
23 map, or of overlaying the road map and the cell map. For purposes of this invention, it may, in some
24 embodiments, not be necessary to keep track of the actual geographic route that a particular stretch of
25 highway takes within a given cell; rather, it may be sufficient to keep track of the cell boundaries that
26 are connected by that stretch of road. These boundary crossings are denoted in FIG. 9 as black dots,
27 but could be denoted in a wide variety of other manners. A highway may be represented as a logical
28 series of cellular boundary points, each point representing the location where the highway coincides
29 with the intersection of two adjoining cells. Within the overlap and variance limits, this represents a
30 specific repeatable geographic region, well within the resolution of the application.

1 For example, Hwy 10 may be represented by the following set of tuples, which may be stored
2 as a linked list, a table, or in any other suitable format:

3 (C1W,C1C2) (C2C1,C2D2) (D2C2,D2D3) (D3D2,D3D4)
4 (D4D3,D4D5) (D5D4,D5E5) (E5D5,E5F5) (F5E5,F5S)

5 In this example, the boundary C1C2 denotes the boundary crossed when going from cell C1
6 to cell C2, while the boundary C2C1 indicates that same boundary but expressed as going from cell
7 C2 to cell C1, or, in other words, from the C2 cell's point of view. The boundary F5S denotes the
8 southern boundary of cell F5, which notation may be used when, for example, a particular cell does
9 not have a neighboring cell at that particular boundary.

10 Hwy 51 might be represented as:

11 (A3C,A3B3) (B3A3,B3C3) (C3B3,Hwy202,C3D3) (D3C3,Hwy10)

12 The notation A3C denotes a location central to or within cell A3, as opposed to one of that
13 cell's boundaries. The third tuple is a triplet including an indication that Hwy 51 intersects with Hwy
14 202 somewhere in cell C3, along the segment that connects the C3B3 boundary crossing to the C3D3
15 boundary crossing.

16 Various other representations are certainly conceivable and within the scope of this invention.

17 Conclusion

18 In various embodiments, the various functionalities described herein may be partitioned in
19 various manners, and may be distributed between the cellular device, traffic analysis system, and/or
20 cellular system in any of a variety of ways.

21 The reader should note that the term "determine" may include "estimate" or "calculate" or
22 other such functionalities.

23 The reader should appreciate that drawings showing methods, and the written descriptions
24 thereof, should also be understood to illustrate machine-accessible media having recorded, encoded,
25 or otherwise embodied therein instructions, functions, routines, control codes, firmware, software, or
26 the like, which, when accessed, read, executed, loaded into, or otherwise utilized by a machine, will
27 cause the machine to perform the illustrated methods. Such media may include, by way of illustration
28 only and not limitation: magnetic, optical, magneto-optical, or other storage mechanisms, fixed or
29 removable discs, drives, tapes, semiconductor memories, organic memories, CD-ROM, CD-R,
30 CD-RW, DVD-ROM, DVD-R, DVD-RW, Zip, floppy, cassette, reel-to-reel, or the like. They may
31

1 alternatively include down-the-wire, broadcast, or other delivery mechanisms such as Internet, local
2 area network, wide area network, wireless, cellular, cable, laser, satellite, microwave, or other
3 suitable carrier means, over which the instructions etc. may be delivered in the form of packets,
4 serial data, parallel data, or other suitable format. The machine may include, by way of illustration
5 only and not limitation: microprocessor, embedded controller, PLA, PAL, FPGA, ASIC, computer,
6 smart card, networking equipment, or any other machine, apparatus, system, or the like which is
7 adapted to perform functionality defined by such instructions or the like. Such drawings, written
8 descriptions, and corresponding claims may variously be understood as representing the instructions
9 etc. taken alone, the instructions etc. as organized in their particular packet/serial/parallel/etc. form,
10 and/or the instructions etc. together with their storage or carrier media. The reader will further
11 appreciate that such instructions etc. may be recorded or carried in compressed, encrypted, or
12 otherwise encoded format without departing from the scope of this patent, even if the instructions
13 etc. must be decrypted, decompressed, compiled, interpreted, or otherwise manipulated prior to their
14 execution or other utilization by the machine.

15 Reference in the specification to "an embodiment," "one embodiment," "some
16 embodiments," or "other embodiments" means that a particular feature, structure, or characteristic
17 described in connection with the embodiments is included in at least some embodiments, but not
18 necessarily all embodiments, of the invention. The various appearances "an embodiment," "one
19 embodiment," or "some embodiments" are not necessarily all referring to the same embodiments.

20 If the specification states a component, feature, structure, or characteristic "may", "might", or
21 "could" be included, that particular component, feature, structure, or characteristic is not required to
22 be included. If the specification or claim refers to "a" or "an" element, that does not mean there is
23 only one of the element. If the specification or claims refer to "an additional" element, that does not
24 preclude there being more than one of the additional element.

25 Those skilled in the art having the benefit of this disclosure will appreciate that many other
26 variations from the foregoing description and drawings may be made within the scope of the present
27 invention. Indeed, the invention is not limited to the details described above. Rather, it is the
28 following claims including any amendments thereto that define the scope of the invention.
29